FOREIGN TECHNOLOGY DIVISION

MEASURING THE PERMEABILITY OF FIBERS MADE FROM ARTIFICIAL MATTER

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ABSTRACT: This report treats of the properties of fiber optics, its use in science and practice and the methods by which the usefulness of macromolecular matter in fiber optics has been realized. In this report the results measured on polymetacrylate and polyamide fibers are compared. English translation: 12 pages.

MEASURING THE PERMEABILITY OF FIBERS MADE FROM ARTIFICIAL MATTER

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Summary

This report treats of the properties of fiber optics, its use in science and practice and the methods by which the usefulness of macromolecular matter in fiber optics has been realized. In this report the results measured on polymetacrylate and polyamide fibers are compared.

Recently in the pages of our periodical, reports appear which describe newly originating lines of optics--fiber optics. We deal here especially in the use of light conductive bars or discs which have already been used in technical practice for some time.

Light conduction by a smooth glass bar or a bar from any other transparent material is made possible by the total reflection of light on the inner walls of the light-conductive bar. For total reflection in the fiber (that is what we will call a very thin bar), the following equation is generally valid (Figure 1)

$$n_1 \sin \varepsilon_m = n_2 \sin \frac{\pi}{2}. \qquad (1)$$

$$\varepsilon_m = \arcsin \frac{n_2}{n_1},$$

where ε_m is the smallest permeable angle of incidence on the fiber wall. For the ray on the fiber, the following condition must then be

$$\varepsilon = \arcsin \frac{n_2}{n_1}, \qquad (2)$$

n_2 is the reflection index in the medium surrounding the fiber; n_1 is the refraction index of the fiber, and ε is the angle of incidence on the wall of the fiber.

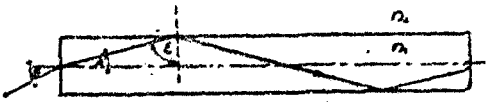

Figure 1.

For a light ray to be able to fulfill this condition, it must fall on the face of the fiber at a definite angle β, which must not exceed the value given by the ratio

$$\sin \beta' = n_1 \sin \beta' = n_1 \cos \varepsilon,$$
$$\beta = \arcsin \sqrt{n_1^2 - n_2^2} \qquad (3)$$

In practice, incidence angles β on the face of the fiber in the range of values from 0° to 10° are used.

In order to preserve the total light reflection on the walls of the fiber, the surface of the fiber must be polished as well as possible, and the fibers must be surrounded by a medium whose refraction index is smaller than the refraction index of the fiber. In practice, this condition is realized so that the fibers are double layers, i. e., they consist of a core and a cover, whereby the core of the fiber has a great refraction index, and the cover has a lower refraction index. These fibers are poured into a special eleastic cement so that bonds will be formed with an oval or circular section with dimensions of perhaps 20 x 50 μ. Then the proper fiber optics form from them, usually in connection with lens optics.

An additional factor which affects the properties of fiber optics is the absorption of light in the fiber material. It is known that glass of a greater refraction index (which is required for fiber cores) is colored; it also has a more substantial absorption, where for example, polymethylmetacrylate has an abosrption in the minimum visible area.

The absorption in the fiber depends on the path of the light ray. This path increases directly portional to the angle of incidence β on the face of the fiber

$$L = \frac{n_1 l}{\sqrt{n_1^2 - \sin^2 \varepsilon}}, \qquad (4)$$

where L is the length of the ray path, and l is the length of the fiber.

Likewise, with angle β the number of reflected rays from the walls of the fiber increases. This number also increases with a reduction in the diameter of the fiber.

The following equation is valid

$$\eta = \frac{l}{d} \frac{\sin \varepsilon}{\sqrt{n_1^2 - \sin^2 \varepsilon}}, \qquad (5)$$

where η is the number of reflections, and d is the diameter of the fiber.

The permeability of the fiber is determined by the coefficient of light permeability given by the relationship

$$\tau = \frac{I}{I_0} \qquad (6)$$

where I is the passing light stream, and I_0 is the incident light current.

The amount of light which will pass through the fiber is given by the expression

$$\frac{dI}{I} = -kaL \qquad (7)$$

$$I = I_0 e^{-\frac{k n_1 l}{\sqrt{n_1^2 - \sin^2 \varepsilon}}}. \qquad (8)$$

where k is the absorption coefficient which includes the absorption coefficient of the fiber material and the absorption coefficient at each reflection.

From these considerations and samples, it is evident that for fiber optics it is necessary to carefully select a material which has low absorption in the given spectral area; its surface is sufficiently polished, and it is sufficiently hard so it will not come to mechanical

damage or surface contamination, which considerably increases light losses or even completely eliminates the passage of light.

It is necessary to emphasize that fiber optics also have certain additional important limitations, e. g., the flexibility of the volume is not arbitrary, and the radius of the bend R must be either equal to or greater than the value given by the sample

$$R = \frac{d}{2} \cdot \frac{2n_2 - n_1}{n_1 - n_2}, \qquad (9)$$

where n_2 is the refraction index in the medium surrounding the fiber; n_1 is the index of the fiber refraction, and d is the diameter of the fiber. An additional limitation is that the section of the fiber cannot be arbitrarily reduced, because with diameters close to the wavelength of light, the wave properties of the light prevent its passage; also light losses increase disproportionately.

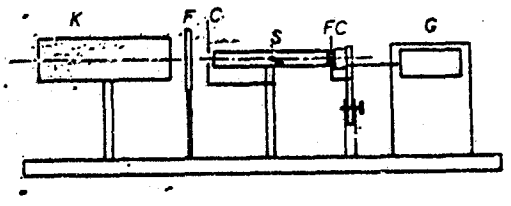

Figure 3.

The use of fiber optics is very extensive. In technical practice, certain TV problems can be solved, e. g., increasing the differentiating ability and picture contrast [1], and enabling the transition of color TV. Fiber optics can also be used in electroluminescent picture amplifiers, where for example, it is possible to amplify the picture with conical fibers. In nuclear technology fiber compositions made from scintillation material can be used for forming and determining detectors for some other particles. Compositions with fiber optics enable reviewing reactor channels, etc. Acoording to reports from Japan and Germany, the photographing of fiber volumes is used as an

addition to photo objectives. In the construction industry, fiber optics are used to study the effectiveness of machines at inaccessible places. Fiber optics will also find great value in quantum light generators. For medicine, fiber optics are of the greatest importance, because it could much more perfectly compensate existing endoscopic devices, which would be flexible and thin, with a great distinguishing ability, and their use would be much less painful.

In 1960, for example, Hett and Curtiss [2] announced that they constructed a ureteroscope which differentiates 20 lines/mm at a length of 70 cm and a thickness of 3.5 mm. The flexibility of the system enabled an examination of the kidney pelvis, which was impossible to attain with other instruments. The system was so optically perfect that it was possible to photograph the organ on 8 mm film. The device was constructed so that the volume representing the system was enveloped in light conductive fibers which conduct the light from its source to the investigated body cavity. According to Lynch [3] it is possible to use fiber optics for the observation of the living heart and the construction of a needle with fiber optics for the study of muscle fibers, blood corpuscles, etc.

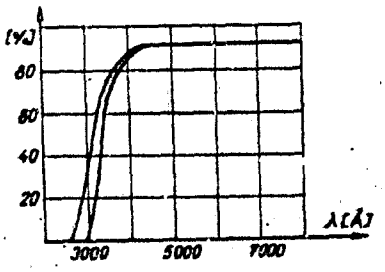

Figure 2.

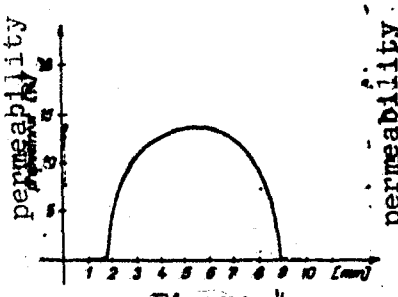

Figure 4.

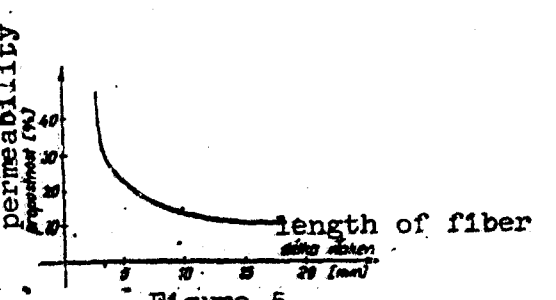

Figure 5.

Materials from which fiber optics are formed must be transparent and lustrous and must fulfill certain mechanical requirements. It is therefore necessary to turn attention from the classical glass materials

[illegible] from plastic matter, which have a constantly greater appli-[illegible]. Of organic substances there are suitable materials manufactured [illegible] basis of polymethylmetacrylate and polyamide, and it is therefore [illegible]ssary to insure whether it is possible actually to form fiber optics [illegible] whether its optical properties are suitable.

Let us list some properties of these organic substances: Polymethylmetacrylate (plexiglass) is a firm and elastic plastic substance with very good mechanical, electrical, optical and chemical properties. It is a thermoplastic substance, and its plasticization temperature depends on the polymeric degree and content of plasticizers. The maximum temperature at which it can be used constantly, is perhaps 80°C. For the purpose of fiber optics, they are used mostly in the form of circular section fibers. Plexiglass is more transparent than crystal glass and will pass a minimum of 92% of the visible light. The graph of the dependence of permeability on the wavelength is given in Figure 2. The amount of the ultraviolet light passed depends on its wavelength, and its terminal value is perhaps 2800 Å for nonsoftened plexiglass, and perhaps 3000 Å for softened plexiglass. The absence of color and the transparency do not change, even with a prolonged light effect. The refraction index at 20°C is 1,490 for nonsoftened material, and 1,495 for softened material. The critical boundary angle for plexiglass-air is about 42°; the relative dispersion is 58, resp. 53.7. Fibers made of plexiglass by traction can be made into greater surface dimensions by refining and polishing.

Polyamides are macromolecular resin products. In industry, there are various types of polyamides produced under the titles: tesil, isotesil, silon, etc. These are thermoplastic, rigid and firm more or less transluscent and colorless (according to type), with a refraction index of 1.50-1.55; they have excellent mechanical properties and are physiologically irreproachable. Their mechanical property depends on

the volume of the crystal phase, and this is again dependent on the method of cooling the smelt. Highly oriented polyamides are rigid and nontransparent; the less oriented ones are flexible and also more transparent. Their strength in traction drops with the humidity content. In distinction from the rest of the thermoplastics, polyamides show greater ductibility and resistance against friction. The treatment temperature according to the type of polyamide is about 200 - 400°C. The permeability of polyamide is lower than in plexiglass.

In our laboratory we explore the possibilities of utilizing organic substances in fiber optics. Among other things, we also measured fibers from plexiglass and from different polyamides. In a later section of this report there are given more detailed data about their measurement.

Measurement was done by two methods, for which we had suitable devices and equipment at our disposal. In both instances the light current energing from the fiber volume was transformed into photocurrent. In the first case we measured this photocurrent with a sensitive mirror galvanometer; in the second case we guided the photocurrent originated by the light incident to the volume and the photocurrent which originated bythe light leaving the volume of fibers to the input of a double-beam oscilloscope, and measured their dimensions. As a radiation receiver, we used either a photoelectric cell or a photomultiplier.

A method of measuring the permeability of fibers by measuring the photocurrent with a galvanometer

A diagram of compiling the equipment and devices for this method is shown in Figure 3. The markings in this picture are: K-collimator, F-interference filter, C-circular disphragm, S-volume of fibers, FC-photon and G-mirror galvanometer (titroscope).

The collimator used consisted of a tube, in which there was an

system of F' = 170 mm and a bulb of 35 W capacity charged with [illegible] from a stabilized source. Behind the collimator an interference filter was installed, which selected only monochromatic light from the entire light spectrum. Circular diaphragm C placed behind it, limited the light current only for the purpose of volume S placed closely behind it; the excess was shaded. Let us disregard the bend on the circular diaphragm. The volume was fixed so that light rays fall on the photon FC provided with a small diaphragm having a diameter aperture of 0.6 mm. The diaphragm limited the light fall on the selected, optimum sensitive area of the photocell and enabled measuring the individual light rays of the rear face of the fiber volume with a magnitude of 0.28^2 mm. The diaphragm and the photon were fixed on a stand which moved in vertical and horizontal directions, by turning a micrometric screw; it was also possible to accurately define the position of the measured points. In our case we measured the emerging light current on straight lines going by the center of the body of the fiber volume at points 0.5 mm apart. This current was guided by the photon to a current whose value we calculated by a mirror galvanometer. All the measuring devices were fed from a stabilized source. First, we have determined what the difference in light intensity is during the passage of light through the volume.

Table 1.

Délka viáken (mm) 1)	Propustnost (%) 2)
17,37	9,91
14,40	13,02
11,49	15,62
6,80	16,44
5,82	20,51
4,42	21,17
3,08	42,49

1) length of fiber, (mm);
2) permeability, (%).

Table 2.

Délka vláken (mm) 1)	Propustnost (%) 2)
396,5	38,3
347,8	42,5
295,9	45,8
248,0	51,3
199,4	56,3
147,1	62,5
95,5	69,0
48,0	93,0

1) length of fiber, (mm)
2) permeability (%).

The photocell was placed behind the fiber volume, and all the points of a straight line passing through the center of the volume were measured. In order to measure the entire volume, measurements were made for several azimuths in the volume and it was determined that light intensity decreases from the center in all directions equally; there was no anomaly.

From the measured photocurrent values which are directly proportional to the light current passed, we formulated a graph (Figure 4). On the ordinate axis we plotted line points with the initial point on the perimeter of the fiber, and on the abscissa axis we plotted the ratios of the photocurrent which correspond to the light currents passed by the incident current. In this way we obtained a point diagram of the measured light intensity of the length of the diameter of the volume. For all azimuths the diagrams were the same.

Then we measured the permeability of the volume in dependence on the length of the volume. The photocell was placed in the center of the volume, and the passing light intensity was measured. After each measurement we reduced the volume, polished the body of the volume, and adjusted the volume in a preparation. From the order of measurement, it was then easy to formulate a graph where we plotted the volume length on the abscissa axis and the permeability values corresponding to the individual volume lengths on the ordinate axis. By this means, we obtained a permeability curve of the fibers depending on the length of the fibers (Figure 5).

A method of measuring the permeability (passability of Fibers a double-beam oscilloscope

The diagram of equipment and installations is given in Figure 6, where the following designations are given: K-collimator, F-interference filter, FC_1 and FC_2-two identical photons, RD-rotational diaphragm

(with four segments), C-circular diaphragm, S-volume of fibers, and O-double beam oscilloscope D 581, with an amplifier.

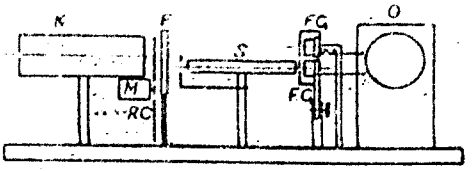

Figure 6.

The rotation diaphragm RC served for interrupting the light current. In this way the signal on the oscillograph picture obtained an approximately oblong characteristic so that it was possible to measure the value of this current well. The photon FC_1 served for creating a so-called normal. The second signal coming from FC_2 (during the use of identical amplification) was smaller by the effect of light losses in the volume. From the ratio of signal magnitude, we determined the premeability. From the values measured, we formulated graphs analogously as we did with the first method.

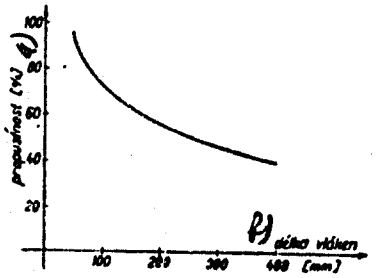

Figure 7.
a) permeability; b) length of fibers.

The convenience of using both methods appeared in the fact, that in both cases we obtained almost identical results, different only in the limits of the errors observed.

We measured the polyamide fibers and the polymethylmetacrylate fibers by both methods, and hwere we give examples of the measurements.

For example, to measure the polyamide we used tesil fibers with a diameter of 350 μm compounded into the volume. The volume with a

diameter of 8 mm, contained 130 fibers. Purified, polished fibers were covered by a thin layer of plexiglass, whose thickness against the diameter of the fiber was insignificant. The volume formed from prepared fibers was poured into a protective cover made of dentacryl. We cleaned and polished the face of the prepared volume. For adjustments of the fiber faces, two abrasive systems were constructed. At each reduction of the fiber volume, it was necessary to grind and polish the face of the volume so that the measurement conditions did not change.

The basic length of a tesil fiber volume was 17.37 mm. We measured these volume lengths: 17.37 mm, 14.40 mm, 11.49 mm, 6.80 mm, 5.82 mm, 4.42 mm, and 3.08 mm. The measured permeability values are given in Table 1. For measurement we selected a light wavelength λ = 550 mm. The permeability graph of tesil fiber volume depending on the length of the volume is given in Figure 7.

Further measurements were made on polymethylmetacrylate fibers. In comparison with tesil fibers, these fibers are much more permeable. Their surface is more polished, and also the quality of the input and output fiber faces is better. In Figure 7 there is shown a fiber permeability curve which depends on their length. Measured values are in Table 2.

Measurements have shown that polymethylmetacrylate is a substance very convenient for fiber optics in the visible area, much better than substances of polyamide. Graphs of both measurements show that the permeability of polyamide is not too convenient for purposes of fiber optics in the visible area of the spectrum. Their mechanical properties are so suitable that it is required for the chemical industry to prepare compounds which would also have good optical properties during the preservation of selective mechanical properties.

Literature

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